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The Regulation of Interdependent Markets

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Abstract

We examine the issue of whether two monopolists which produce substitutable goods should be regulated by one (centralization) or two (decentralization) regulatory authorities, when the regulator(s) can be partially captured by industry. Under full information, two decentralized agencies - each regulating a single market - charge lower prices than a unique regulator, making consumers better off. However, this leads to excessive costs for the taxpayers who subsidize the firms, so that centralized regulation is preferable. Under asymmetric information about the firms' costs, lobbying induces a unique regulator to be more concerned with the industry's interests, and this decreases social welfare. When the substitutability between the goods is high enough, the firms' lobbying activity may be so strong that decentralizing the regulatory structure may be social welfare enhancing.

Keywords: regulation, lobbying, asymmetric information, energy markets.

JEL classification: D82, L51.

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1. Introduction

Should a country set up an energy regulator or rather have separate agencies for gas and electricity? And should we have a single transport authority, or rather a railways regulator separate from those regulating motorways or airports? Our paper provides an attempt to explore these issues, focusing our attention on the *regulatory structure* and on how to design the jurisdiction of a regulatory authority when there are two different but related markets.

Several theoretical contributions to the literature on regulation have investigated the pattern of government intervention in a single product market, whose features hinder unfettered competition between firms. Those studies which have actually considered the regulation of multiproduct industries have been mostly concerned with the problem of determining which firms will supply which products.[1] Our focus is thus not on the number of firms, but on the *number of regulators*.

We assume that a benevolent political principal (the Congress) can delegate the regulation of two interdependent markets either to a unique regulator (a regime defined as *centralization*) or to two different authorities (*decentralization*). Regulation may be non-benevolent since it can be captured by the firms' lobbying activities. Our model predicts that under complete information, where lobbying is *not* profitable, regulatory centralization is the best option for the Congress. As long as regulation is benevolent, market interdependence implies that the centralized (cooperative) regime allows one to internalize all the relevant effects and thus improves social welfare. This intuitive result covers a distributional issue of some interest: decentralizing the regulation yields higher quantities than under centralization, making consumers better off. However, this leads to excessive costs for the taxpayers, who subsidize the firms, and this is detrimental to social welfare.

If firms have private information about their costs, there is scope for lobbying and we find that a unique regulator is more distorted to the industry's interests as a result of the competition between firms at the lobbying stage. A trade-off emerges in equilibrium between the *market interdependence effect* and the *lobbying effect*. When the substitutability between goods is high enough, the latter effect may outweigh the former, so that decentralizing the regulatory structure can increase social welfare. The decentralized (noncooperative) regime turns out to be a good structural response to non-benevolent regulation since it alleviates the capture problem.

The design of the regulatory jurisdiction in interdependent markets is an

[1] See, among others, Gilbert and Riordan [**9**] for an analysis of the advantages and disadvantages of bundled and unbundled supply in multiproduct industries.

issue which, despite its theoretical and empirical importance, has been only touched by the literature on optimal regulation, so that several gaps remain.[2]

The issue of the separation of powers has indeed been addressed in the theory of regulation. Among others, Laffont and Martimort [**12**] consider the problem of monitoring a regulated firm which has private information about some pieces of its activity. The authors argue that when regulation makes collusive offers that are accepted by the firm whatever its characteristics, splitting regulatory rights on some aspects of the firm's performance between different agencies may act as a device against the threat of regulatory capture. Separation turns out to be desirable since it reduces regulatory discretion in engaging in socially wasteful activities. In our setting, we show that decentralized regulation can mitigate the adverse effect of lobbying in a context of interdependent markets since the noncooperative regulatory behavior removes the competition between firms at the lobbying stage.[3]

Another stream of literature which is relevant for our work is the multiprincipal incentive theory. Baron [**2**] examines the regulation of a nonlocalized externality by two different agencies and compares the noncooperative equilibrium with the case in which the two regulators are allowed to coordinate their activities. Contrary to our paper, regulatory agencies represent conflicting interests since they have different mandates. Moreover, lobbying by industry is not an issue. In a reduced-form model with two agencies which exhibit different objectives in presence of regulatory capture, Martimort [**15**] shows that the duplication of non-benevolent regulators may improve social welfare. This shares some similarities with our analysis, even though our results are driven by market interdependence by endogenizing the lobbying stage.

Our model is finally related to the well-known capture theory of economic regulation, whose seminal contribution traces back to Stigler [**20**]. Following his paradigm, we assume that the industry is able to mobilize regulatory

[2] For a recent survey, see Armstrong and Sappington [**1**].

[3] A relevant stream of literature analyzes the trade-off between centralization and decentralization in economic organizations (see Poitevin [**18**] for a review on this topic). Laffont and Martimort [**11**] show that under certain conditions a decentralized structure can alleviate the problem of collusion if there are limits on communication between the principal and the agents. With this literature we share the assumption that the delegation process is imperfect, so that regulators may have private agendas. However, their results are driven by very different forces from those operating in our setting: decentralization (that they call "delegation") implies an extention of the organizational hierarchy, which can be profitable when the principal cannot communicate with the bottom-level agent. In our model, decentralization means separation of the regulatory jurisdiction between two noncooperative agencies and its superiority in terms of social welfare is a consequence of the way the interdependence between markets affects the lobbying stage.

powers to obtain favours, since it has greater incentives than dispersed consumers and taxpayers with a low per-capita stake to get organized in order to exercise political influence.[4] Obviously, regulated firms must incur some costs when lobbying the agency (Laffont and Tirole [**13**]). Following Martimort [**15**], we assume that the capture can only be partial, and that it materializes in a higher weight which the regulator puts on profits in her objective function.[5]

The plan of the paper is as follows. Section 2 presents the basic structures of the model. In Section 3 we compute the full information pricing policies and we study their impact on the welfare of the agents involved. In Section 4 we derive the regulatory outcome under both regimes in the case of asymmetric cost information and make the welfare comparisons. Finally, Section 5 is devoted to some concluding remarks.

2. The basic model

We consider two symmetric markets for substitutable goods. Following Singh and Vives [**19**], the consumers' gross utility from the marketplace is represented by a quadratic utility function of the form

$$U\left(q_1,q_2\right)=\alpha q_1+\alpha q_2-\frac{1}{2}\left(\beta q_1^2+2\gamma q_1q_2+\beta q_2^2\right), \tag{1}$$

where q_i denotes the quantity for good $i=1,2$ and α, β are positive parameters; $\gamma\in[0,\,\beta)$ expresses the degree of substitutability between goods.[6]

The consumer surplus net of expenditures on goods is given by

$$CS\left(q_1,q_2\right)=U\left(q_1,q_2\right)-p_1q_1-p_2q_2. \tag{2}$$

The inverse demand function $p_i\left(q_i,q_j\right)$ for good i is thus[7]

[4] It is anyway worth quoting the contribution of Miller III *et al.* [**16**] who informally argue that centralization should alter the relative rates of return to lobbying for various coalitions, generally in favour of groups having diffuse interests which can focus their lobbying against rent-creating regulation on one location rather than splitting those efforts among a variety of regulatory agencies.

[5] Addressing a different issue, Calzolari and Scarpa [**7**] also suggest that the firm can induce the regulator to be biased towards profits.

[6] All these assumptions ensure that $U\left(.\right)$ is strictly concave and guarantee the positivity of direct demand functions $q_1\left(.\right)$ and $q_2\left(.\right)$ not derived here.

[7] Vives [**22**, ch. 6] shows analytically that, under some basic conditions, if two goods are gross substitutes, which means $\frac{\partial D_i(p)}{\partial p_j}\geq 0$, $i\neq j$, where $D_i\left(p\right)=q_i$ is the direct demand for good i and p is the price vector, then we have $\frac{\partial P_i(q)}{\partial q_j}\leq 0$, $i\neq j$, where $P_i\left(q\right)=p_i$ is the inverse demand for good i and q is the quantity vector.

$$p_i(q_i, q_j) = \alpha - \beta q_i - \gamma q_j. \tag{3}$$

The markets are run by monopolies. The profit of firm i is

$$\pi_i(q_i, q_j, S_i) = p_i(q_i, q_j) \cdot q_i + S_i - C_i(q_i), \tag{4}$$

where S_i is the subsidy which may accrue to firm i via the regulatory process (see below). The total cost of firm i is

$$C_i(q_i) = c_i q_i + f_i, \tag{5}$$

where $c_i \in (0, \alpha)$ is the marginal cost of firm i and $f_i > 0$ is firm i's fixed cost of production. We will later concentrate on symmetric equilibria (where $c_1 = c_2 = c$ and $f_1 = f_2 = f$).

In line with the literature, the Congress is a benevolent maximizer of a social welfare function, which is given by

$$W(q_1, S_1; q_2, S_2) = CS(q_1, q_2) - S_1 - S_2. \tag{6}$$

This means that the Congress cares about consumer surplus net of the subsidization of firms financed by taxpayers via the regulatory process.[8]

Regulator(s) can be partially captured by industries. Following Martimort [**15**], the result of such a partial capture is that the regulatory activity is distorted to industry's interests. The regulatory objective function is then the sum of social welfare W in (6) and (a share of) the profits π_i in (4).

A decentralized regulator for market i only cares about the profit of firm i, to which she attaches a weight equal to $\varphi_i^D \in [0, 1]$,[9] while centralized regulation gives a weight φ_i^C to the profits of each firm. Formally, a decentralized regulator for market i maximizes

$$V_i^D(q_i, S_i; .) = CS(q_i, q_j) - S_i - S_j + \varphi_i^D \pi_i \tag{7}$$

[8] Baron [**3**] shows that if there is a strong electoral connection between the benefits delivered to constituents and their electoral support, the legislature will choose a regulatory mandate that favors consumer over producer interests and results in regulation that does *not* maximize expected total surplus. The Congress' objective can be also thought as a response to the regulatory capture. In our setting of imperfect delegation, the Congress does not have time, resources and expertise to discover the lobbying activity exerted by the firms and it cannot give the regulator the right monetary incentives to completely internalize its objectives. Neven and Röller [**17**] suggest that when competition authority's officials are exposed to the lobbying of firms that can offer them personal rewards a consumer welfare standard might counterbalance the bias resulting from such lobbying.

[9] In other words, it would be too costly for one firm to lobby the regulator in the other market.

and the objective of a unique regulator is

$$V^C(q_1, S_1; q_2, S_2) = CS(q_1, q_2) - S_1 - S_2 + \varphi_1^C \pi_1 + \varphi_2^C \pi_2. \tag{8}$$

The regulatory instruments are the quantity and the subsidy to the firm in each market. Even though in some sectors price regulation seems to be more natural, in relevant industries like electricity, gas and transport, which are characterized by network assets with limited capacity, the choice of scale plays a crucial role as it yields transmission constraints. A common way in the literature to model this feature is to consider the quantity as a choice variable since the entire capacity is dumped on the market.[10] Notice that this formulation implies a sort of quantity competition between regulators under decentralization. This is in line with empirical works of some relevance, which corroborate the idea that binding infrastructure capacity restrictions induce Cournot behavior.[11]

It is worth stressing that the choice of the objective function is not central to our analysis and the results we obtain. Nothing substantial would change in our results, if we assumed that the Congress were to set an objective function with a positive weight on profits, and firms lobby to increase that weight in the regulatory objective function(s). In the same way, the regulatory problems would not be affected, if we assumed that each regulator only cares about the subsidization of her regulated firm.[12]

The weights φ_i^D and φ_i^C are driven by the firms' lobbying activities. These weights depend on the amount of expenditure incurred to influence the agency, which is financed through profits that the firm receives in equilibrium. In other terms, the regulator's concern φ_i^k in regime k $(k = C, D)$ with the rent of firm i is the outcome of the following maximization problem

$$\max_{\varphi_i^k \in [0,1]} \left[\pi_i^k \left(\varphi_i^k, \varphi_j^k \right) - \nu \left(\varphi_i^k \right) \right], \tag{9}$$

where $\nu(.) \geq 0$ (with $\nu(0) = 0$) is the cost (identical for both firms) of lobbying activity, which is increasing and convex in φ_i^k $(\nu' > 0,\ \nu'' > 0)$. This setting captures the idea originated by Stigler [**20**] that interest groups choose to influence the government at a level where their marginal benefit equals their marginal cost.

[10] See on this topic Tirole [**21**, ch. 5].

[11] See Egging and Gabriel [**8**] and Holz *et al.* [**10**] for empirical evidence about the European natural gas market. Bushnell *et al.* [**6**] focus on the U.S. electicity sector.

[12] The subsidy of the other firm represents an exogenous variable in the regulator's optimization program, which disappears in the first-order condition.

3. The full information benchmark

In each market the regulatory agency has two instruments, i.e. quantity q_i and subsidy S_i to firm i. Under complete information the timing of the regulatory game is the following.

(I) The Congress decides to delegate regulation of two interdependent markets either to a unique agency or two different authorities.

(II) Firms engage in a lobbying activity to induce the regulator(s) to internalize (at least in part) their profits in the objective function.

(III) Under decentralization the regulator for market i independently makes a take-it-or-leave-it offer of a regulatory mechanism $M_i^D = \left\{q_i^D, S_i^D\right\}$ to firm i. Under centralization the unique agency simultaneously offers a regulatory policy $M_i^C = \left\{q_i^C, S_i^C\right\}$ to each firm.

(IV) Each firm can either accept or reject the offer. If it refuses the proposed policy, the firm does not produce and earns zero profits.

(V) If the firm accepts, the contract is executed and the regulatory policy is implemented.

Our regulatory model is a two-stage game. At the first stage, the firms' lobbying activity determines the weight of profits in the regulatory objective function(s). At the second stage, each regulator chooses the policy which maximizes her objective function. We solve this game by backward induction. The two alternatives we consider differ in the number of markets (or firms) the regulator is responsible for and (possibly) the value assigned to profits. Let us analyze them in sequence.

3.1. Prices under decentralization

Let us first consider the regulatory setting in which two different agencies coexist. We label this environment as *decentralization*.

At the final stage, the regulator in charge of market i sets the quantity q_i and the subsidy S_i, in order to maximize the consumer surplus CS net of subsidies $(S_1 + S_2)$ plus the profits of firm i weighted by a given parameter $\varphi_i^D \in [0, 1]$ determined at the previous stage, which represents the value the regulator assigns to each dollar of firm i's rent. Substituting (2) and (4) into (7), the objective of the regulator for market i is the following

$$\max_{q_i, S_i} \alpha q_i + \alpha q_j - \frac{1}{2}\left(\beta q_i^2 + 2\gamma q_i q_j + \beta q_j^2\right) - p_i\left(q_i, q_j\right) \cdot q_i$$

$$-p_j\left(q_i, q_j\right) \cdot q_j - S_i - S_j + \varphi_i^D \pi_i \qquad (10)$$

$$s.t. \quad \pi_i \geq 0, \tag{PC$_i$}$$

where the participation constraint (PC_i) states that firm i is willing to produce only if it receives from the regulatory mechanism at least its reservation profit (normalized to zero). Referring to Appendix A for the details, from the first-order condition for q_i the regulated quantity for good i is given by

$$q_i^D \equiv q^D = \frac{\alpha - c}{\beta}. \tag{11}$$

Replacing (11) into (3) yields the full information pricing policy. This result is emphasized in the following Lemma.

Lemma 1 *Under complete information, decentralized regulation yields a price for good i equal to*

$$p_i^D \equiv p^D = c - z\left(\alpha - c\right), \tag{12}$$

where $z \equiv \frac{\gamma}{\beta} \in [0, 1)$.

Notice from (12) that as markets are independent ($z = 0$) we find the standard marginal cost pricing. As $c \in (0, \alpha)$, the substitutability between the goods ($z > 0$) reduces equilibrium prices *below* marginal costs.

At the first stage, each firm engages in a lobbying activity, which determines the weight the regulator is willing to attach to profits. As specified above, we assume that this weight depends on the amount of expenditure incurred to influence the agency. In other words, in line with (9) the regulator's concern φ_i^D with the rent of firm i is the outcome of the following maximization problem

$$\max_{\varphi_i^D \in [0,1]} \left[\pi_i^D\left(\varphi_i^D, \varphi_j^D\right) - \nu\left(\varphi_i^D\right)\right]. \tag{13}$$

Since $\varphi_i^D \in [0, 1]$ and then there is no reason to leave the firm any rents, i.e. $\pi_i^D = 0$, it is immediate to see that $\varphi_1^D = \varphi_2^D \equiv \varphi^D = 0$ in equilibrium. In other words, no firm has incentives to lobby the regulator, since it anticipates that it will get zero profits anyway.

3.2. The case of centralization

The alternative regulatory environment we consider is one where a single agency is given the responsibility for both markets. We label this environment as *centralization.*

At the second stage, this regulator determines the quantities q_1 and q_2 and subsidies S_1 and S_2 in order to maximize the regulator's objective function. Replacing (2) and (4) into (8), the regulator's program is the following

$$\max_{q_1,q_2,S_1,S_2} \alpha q_1 + \alpha q_2 - \frac{1}{2}\left(\beta q_1^2 + 2\gamma q_1 q_2 + \beta q_2^2\right)$$

$$-p_1(q_1,q_2)\cdot q_1 - p_2(q_1,q_2)\cdot q_2 - S_1 - S_2 + \varphi_1^C \pi_1 + \varphi_2^C \pi_2 \tag{14}$$

$$s.t. \quad (PC_1),\ (PC_2).$$

Appendix B shows the solution to the problem in (14). From the first-order condition for q_i the regulated quantity for good i is given by

$$q_i^C \equiv q^C = \frac{\alpha - c}{\beta(1+z)}. \tag{15}$$

We can see from (15) that substitutability reduces the equilibrium output. A unique regulator finds it optimal to curb production of substitutes, since consumers can move from one market to the other.

Let us now derive the complete-information pricing policy under regulatory centralization. This is shown in the following Lemma.

Lemma 2 *Under complete information, centralized regulation yields a price for good i equal to*

$$p_i^C \equiv p^C = c. \tag{16}$$

Observe from (16) that the price set by a single regulator equals marginal costs, independently of substitutability between goods.

As under decentralization, at the first stage lobbying occurs which yields the weight given to profits in the regulatory objective function. Hence, the regulatory concern φ_i^C with profits of firm i is the outcome of the following maximization problem

$$\max_{\varphi_i^C \in [0,1]} \left[\pi_i^C\left(\varphi_i^C, \varphi_j^C\right) - \nu\left(\varphi_i^C\right)\right]. \tag{17}$$

Since $\pi_i^D = 0$, even under centralization lobbying activity is not profitable in case of complete information and then $\varphi_1^C = \varphi_2^C \equiv \varphi^C = 0$.

From the analysis above we can conclude that

$$\Delta\varphi = \varphi^D - \varphi^C = 0, \tag{18}$$

so that in both regimes lobbying does not emerge in equilibrium. This confirms the well-known idea that in absence of asymmetric information, regulated firms are unable to extract rents and therefore have no incentives to influence regulatory outcomes.

3.3. Welfare comparisons

Let us now compare the welfare of each agent affected by the regulatory outcome under the two regimes. We start comparing price levels, which turn out to be crucial for the analysis of our main results. Taking the difference between prices in (12) and (16) immediately yields

$$p^D - p^C \equiv \Delta p = -z(\alpha - c) = -I(z), \tag{19}$$

where

$$I(z) \equiv z(\alpha - c) \geq 0 \tag{20}$$

as $c \in (0, \alpha)$. Notice that (19) is negative as long as goods are substitutes. We know from (16) that prices under centralization are not affected by substitutability. On the contrary, (12) shows that with market interdependence - as consumers can switch from one good to the other - the noncooperative behavior of regulators pushes prices below marginal costs. Hence, a "*market interdependence effect*", denoted by $I(z)$, occurs under full information and yields a *downward* price distortion under decentralization that definitely benefits consumers.

We can show now our first relevant results, which will be proved and commented upon in different steps.

Proposition 3 *Assume that $z \in (0, 1)$, i.e. goods are substitutes. Then, under complete information, regulatory decentralization*

(i) increases consumer surplus, i.e. $CS^D > CS^C$

(ii) increases subsidies, i.e. $S^D > S^C$

(iii) decreases social welfare, i.e. $W^D < W^C$.

Starting from point (i) in Proposition 3, we plug (11) and (15) into (2) in order to find the difference in consumer surplus between the two regulatory regimes, which after some manipulations can be written as

$$CS^D - CS^C \equiv \Delta CS = z\frac{2+z}{\beta(1+z)}(\alpha - c)^2. \tag{21}$$

Substitutability between goods implies that expression (21) is strictly positive ($CS^D > CS^C$), so decentralization makes consumers better off. This is a straightforward consequence of lower prices under this regime, as is evident from (19).

Coming to subsidies, notice that regulated prices are lower under decentralization, but equilibrium profits are zero in all cases. This can work because of subsidies which are bound to be lower under centralized regulation. To be more precise, let us now compute the amount of subsidies the firms receive (to show point (*ii*) in Proposition 3). Substituting (11) and (15) into (4), we obtain after some computations the difference in subsidies granted to each firm between the two regulatory regimes, which is given by

$$S^D - S^C \equiv \Delta S = \frac{z}{\beta} (\alpha - c)^2 . \tag{22}$$

Not surprisingly, (22) shows that the higher production under decentralization requires a greater subsidization ($S^D > S^C$) which reduces taxpayer welfare.

As from (6) the Congress cares about the consumer surplus net of subsidies financed by taxpayers, using (21) and (22) the difference in social welfare between the two regimes can be written after some computations as

$$W^D - W^C \equiv \Delta W = -\frac{z^2}{\beta (1+z)} (\alpha - c)^2 . \tag{23}$$

Notice from (23) that, as we have emphasized in point (*iii*) of Proposition 3, substitutability between goods yields higher social welfare under centralization ($W^D < W^C$). The excess subsidy given under decentralization entails a welfare loss which more than compensates the higher consumer surplus.

In a sense, this is the result one would have expected. Under complete information, nothing interferes with the regulator's ability to maximize her objective function which, as long as $\varphi \in [0, 1]$, entails that profits are zero independently of the weight each regulator gives to the private firm's profits (see Baron and Myerson [**5**]). Therefore, lobbying is not profitable, and having one powerful regulator, in charge of both markets, yields a better outcome. However, what we consider striking is that the (predictable) aggregate result conceals a relevant distributional issue: consumers would be better off with two independent regulators, but this would happen at an excessively large cost for taxpayers.

4. Prices under asymmetric information

Let us now assume that each firm has private information about its marginal cost c_i. The regulator has only imperfect prior knowledge about c_i, represented by a density function $f(c_i)$, which is assumed to be continuous and positive on the domain $[c^-, c^+]$. The corresponding cumulative distribution function is given by $F(c_i) = \int_{c^-}^{c_i} f(\widetilde{c}_i)\, d\widetilde{c}_i \in [0, 1]$.

Under asymmetric information the timing of the regulatory game is the following.

(I) Nature draws an independently and identically distributed type c_i for firm i, according to the density function $f(c_i)$.

(II) Firms engage in a lobbying activity to induce the regulator(s) to internalize (at least in part) their profits in the objective function.

(III) Each firm learns its type.

(IV) Under decentralization, each regulator independently offers a direct incentive compatible mechanism $M_i^D = \left\{q_i^D(\widehat{c}_i), S_i^D(\widehat{c}_i)\right\}$ where the output $q_i(.)$ and the subsidy $S_i(.)$ targeted to firm i are contingent on its own report $\widehat{c}_i \in [c^-, c^+]$. Each firm is induced to reveal honestly its private information, so that in equilibrium we have $\widehat{c}_i = c_i$.[13] Under centralization, a unique regulator can make the regulatory policy contingent on the declarations of both firms, so she simultaneously offers $M_i^C = \left\{q_i^C(\widehat{c}_i, \widehat{c}_j), S_i^C(\widehat{c}_i, \widehat{c}_j)\right\}$.

(V) Each firm can either accept or reject the offer. If it refuses the proposed policy, the firm does not produce and earns zero profits.

(VI) If the firm accepts, the contract is executed and the regulatory policy is implemented.

As shown in Appendix C, a local necessary condition for incentive compatibility, which is also globally sufficient if $q_i(.)$ is non-increasing in c_i, is given by the following expression

$$\int_{c^-}^{c^+} \pi_i(c_i,.)\, f(c_j)\, dc_j = \int_{c^-}^{c^+} \pi_i\left(c^+,.\right) f(c_j)\, dc_j + \int_{c^-}^{c^+}\int_{c_i}^{c^+} \frac{\partial C_i(\widetilde{c}_i,.)}{\partial \widetilde{c}_i} d\widetilde{c}_i f(c_j)\, dc_j. \tag{ICC$_i$}$$

This condition states that the expected profit of firm i must be equal to the expected profit of the most inefficient firm plus an expected informational rent (captured by the double integral) which represents the reward to the firm for revealing truthfully its private information. Notice that, as markets are interdependent, when signing the contract each firm can only predict the expected value of its profit, which depends on the costs of the other firm.

[13] The *revelation principle* ensures that, without any loss of generality, the regulator may be restricted to direct incentive compatible policies, which require the firm to report its cost parameter and which give the firm no incentive to lie. For an application of the revelation principle to regulation, see the seminal paper of Baron and Myerson [**5**].

4.1. Prices with decentralization

A decentralized regulator maximizes (7) in expected terms since she designs the policy mechanism before knowing the firm's cost. Using (2) and (4), at the second stage the maximization problem is the following

$$\max_{q_i(c_i),S_i(c_i)} \int_{c^-}^{c^+}\int_{c^-}^{c^+} \Big[\alpha q_i(c_i) + \alpha q_j(c_j) - \frac{1}{2}\left(\beta q_i^2(c_i) + 2\gamma q_i(c_i)\cdot q_j(c_j) + \beta q_j^2(c_j)\right)$$

$$-p_i(q_i(c_i), q_j(c_j))\cdot q_i(c_i) - p_j(q_i(c_i), q_j(c_j))\cdot q_j(c_j)$$

$$-S_i(c_i) - S_j + \varphi_i^D \pi_i\Big] f(c_i) f(c_j)\, dc_i dc_j, \quad s.t. \tag{24}$$

$$\int_{c^-}^{c^+} \pi_i(c_i, .) f(c_j)\, dc_j \geq 0 \tag{PC$_i$}$$

$$\int_{c^-}^{c^+} \pi_i(c_i, .) f(c_j)\, dc_j = \int_{c^-}^{c^+} \pi_i\left(c^+, .\right) f(c_j)\, dc_j + \int_{c^-}^{c^+}\int_{c_i}^{c^+} q_i(\widetilde{c}_i)\, d\widetilde{c}_i f(c_j)\, dc_j, \tag{ICC$_i$}$$

where the incentive compatibility constraint (ICC$_i$) of firm i is derived for the cost specification in (5). Appendix D shows the solution to the problem in (24).

From the first-order condition for $q_i(.)$ the quantity produced by firm i as a function of φ_i^D is given by

$$\overline{q}_i^D\left(\varphi_i^D\right) = \frac{1}{\beta}\left[\alpha - c_i - \left(1-\varphi_i^D\right) H_i\right], \tag{25}$$

where $H_i \equiv \frac{F(c_i)}{f(c_i)} \geq 0$ is the hazard rate.[14]

For the sake of convenience, we focus our attention on the symmetric case,[15] i.e. $c_1 = c_2 = c$. Replacing (25) into (3) yields the asymmetric information prices as functions of the profit weights, which are shown in the following Lemma.

[14] The hazard rate H_i is supposed to be increasing in c_i. This monotonicity property, which is met by the most usual distributions, may be interpreted as a decrease in the conditional probability that there are further cost reductions, given that there has already been a cost marginal reduction, as the firm becomes more efficient. See Laffont and Tirole [**14**, ch. 1] for a description of this "decreasing return" assumption.

[15] Notice however from Appendix D that the two cost parameters are independently drawn from the distribution of costs.

Lemma 4 *Under asymmetric cost information, decentralized regulation yields a price for good i equal to*

$$\begin{aligned}\overline{p}_i^D\left(\varphi_i^D,\varphi_j^D\right) &= c - z\left(\alpha - c\right) + H\left[\left(1-\varphi_i^D\right) + z\left(1-\varphi_j^D\right)\right] \\ &= p^D + H\left[\left(1-\varphi_i^D\right) + z\left(1-\varphi_j^D\right)\right], \qquad (26)\end{aligned}$$

where p^D is defined by (12).

The impact of substitutability on prices is now twofold. On the one hand, as under full information, higher substitutability yields a reduction in prices. On the other, the distortion above the complete-information price, captured by the expression in square brackets, is exacerbated by the substitutability between goods. To see which effect prevails, notice from (26) that

$$\frac{\partial \overline{p}_i^D}{\partial z} = -\left[\alpha - c - \left(1-\varphi_j^D\right)H\right] < 0,$$

as $\overline{q}_j^D > 0$ (see (25) inverting i and j). As under complete information, even though at a lesser extent, given φ_j^D a stronger substitutability between goods reduces prices in equilibrium.

Finally, notice that an increase in the weight φ_j^D given to the profits of the firm j yields a reduction in the equilibrium price $\overline{p}_i^D$ as long as goods are substitutes. Indeed, a higher quantity produced in market j when the regulator is more profit distorted decreases the price for the substitutable good i (see (3)).

4.2. Pricing policy under centralization

Substituting (2) and (4) into (8) evaluated in expected terms, the maximization program of a unique regulator under asymmetric information is the following

$$\max_{q_1(c_1,c_2),q_2(c_1,c_2),S_1(c_1,c_2),S_2(c_1,c_2)} \int_{c^-}^{c^+}\int_{c^-}^{c^+} \left[\alpha q_1\left(c_1,c_2\right) + \alpha q_2\left(c_1,c_2\right)\right.$$

$$-\frac{1}{2}\left(\beta q_1^2\left(c_1,c_2\right) + 2\gamma q_1\left(c_1,c_2\right)\cdot q_2\left(c_1,c_2\right) + \beta q_2^2\left(c_1,c_2\right)\right)$$

$$\left.-p_1\left(q_1\left(c_1,c_2\right),q_2\left(c_1,c_2\right)\right)\cdot q_1\left(c_1,c_2\right) - p_2\left(q_1\left(c_1,c_2\right),q_2\left(c_1,c_2\right)\right)\cdot q_2\left(c_1,c_2\right)\right]$$

$$-S_1(c_1,c_2) - S_2(c_1,c_2) + \varphi_1^C \pi_1 + \varphi_2^C \pi_2\big] f(c_1) f(c_2) \, dc_1 dc_2 \tag{27}$$

$$s.t. \quad (PC_1),\ (PC_2),\ (ICC_1),\ (ICC_2).$$

Notice that with independently and identically distributed cost draws the incentive compatibility constraints under centralization are a straightforward extension of those derived in Appendix C for the case of decentralization. The only difference is that now the quantity is contingent on the declaration of both firms. Appendix E shows the solution to the problem in (27).

From the first-order condition for $q_i(.)$, restricting our attention on the symmetric case ($c_1 = c_2 = c$) the regulated quantity for good i as a function of φ_i^C and φ_j^C can be written after some manipulations as

$$\overline{q}_i^C\left(\varphi_i^C, \varphi_j^C\right) = \frac{1}{\beta(1+z)}\left[\alpha - c - \left(1 - \varphi_i^C\right)H\right] + z\frac{\varphi_i^C - \varphi_j^C}{\beta(1-z^2)}H. \tag{28}$$

Notice from (28) that

$$\frac{\partial \overline{q}_i^C}{\partial \varphi_j^C} = -\frac{z}{\beta(1-z^2)}H \leq 0. \tag{29}$$

Centralized regulation brings about a sort of competition between the firms, which has implication for their lobbying activities. A higher weight obtained by firm j on its profits harms firm i, which is allowed to produce (and earn) less, as the goods are substitutes.

We are now in a position to derive the asymmetric information prices as a function of profit weights. This is done in the following Lemma.

Lemma 5 *Under asymmetric cost information, centralized regulation yields a price for good i equal to*

$$\overline{p}_i^C\left(\varphi_i^C\right) = c + \left(1 - \varphi_i^C\right)H. \tag{30}$$

Notice from (30) that the price charged by a single regulator is distorted above marginal costs due to asymmetric information, independently of the substitutability between goods. Hence, in both regulatory structures asymmetric information increases prices. However, under centralization the regulated price is above marginal cost, while this is not necessarily the case under decentralization (see (26)).

4.3. Equilibrium lobbying activities

Now that we have derived the equilibrium prices/quantities in the regulation stage (as functions of the profit weights φ_i^k, with $k = C, D$), we can proceed backwards to determine the equilibrium levels of lobbying activities, using (9). To this end, we need to calculate the expected profits on the basis of equilibrium quantities, as lobbying is assumed to take place before firms learn their private information.

In case of decentralization, after substituting the equilibrium profit from (ICC$_i$), as determined by (25), into (9) we can derive the weight given by each agency to the profits of firm i as the solution to

$$\max_{\varphi_i^D \in [0,1]} \int_{c^-}^{c^+} \int_{c^-}^{c^+} \int_{c}^{c^+} \frac{1}{\beta} \left[\alpha - \widetilde{c} - \left(1 - \varphi_i^D\right) H\left(\widetilde{c}\right) \right] d\widetilde{c} f\left(c_i\right) f\left(c_j\right) dc_i dc_j - \nu\left(\varphi_i^D\right). \tag{31}$$

The (interior) equilibrium value for φ_i^D must satisfy the following first-order condition

$$\nu'\left(\overline{\varphi}_i^D\right) = \frac{1}{\beta} \int_{c^-}^{c^+} \int_{c^-}^{c^+} \int_{c}^{c^+} H\left(\widetilde{c}\right) d\widetilde{c} f\left(c_i\right) f\left(c_j\right) dc_i dc_j,$$

which states that the equilibrium weight is such that the marginal cost of lobbying equates the (expected) marginal profit. This implies

$$\overline{\varphi}_i^D \equiv \overline{\varphi}^D = \left(\nu'\right)^{-1} \left(\frac{\widetilde{H}}{\beta} \right), \tag{32}$$

where $\widetilde{H} \equiv \int_{c^-}^{c^+} \int_{c^-}^{c^+} \int_{c}^{c^+} H\left(\widetilde{c}\right) d\widetilde{c} f\left(c_i\right) f\left(c_j\right) dc_i dc_j$. Notice from (32) that the two firms obtain the same weight on their profits, i.e. $\overline{\varphi}_i^D \equiv \overline{\varphi}^D$, $i = 1, 2$.

Turning to the case of centralization, we can proceed in an analogous way using (28) and (9). The weight given to profits by a unique regulator arises from the following maximization

$$\max_{\varphi_i^C \in [0,1]} \int_{c^-}^{c^+} \int_{c^-}^{c^+} \int_{c}^{c^+} \frac{1}{\beta\left(1+z\right)} \left[\alpha - \widetilde{c} - \left(1 - \varphi_i^C\right) H\left(\widetilde{c}\right) \right.$$
$$\left. + z \frac{\varphi_i^C - \varphi_j^C}{1 - z} H\left(\widetilde{c}\right) \right] d\widetilde{c} f\left(c_i\right) f\left(c_j\right) dc_i dc_j - \nu\left(\varphi_i^C\right). \tag{33}$$

The (interior) equilibrium value for φ_i^C must satisfy the following first-order condition

$$\nu'\left(\overline{\varphi}_i^C\right) = \frac{1}{\beta\left(1-z^2\right)} \int_{c^-}^{c^+}\int_{c^-}^{c^+}\int_{c}^{c^+} H\left(\widetilde{c}\right) d\widetilde{c} f\left(c_i\right) f\left(c_j\right) dc_i dc_j,$$

which implies

$$\overline{\varphi}_i^C \equiv \overline{\varphi}^C = \left(\nu'\right)^{-1}\left(\frac{\widetilde{H}}{\beta\left(1-z^2\right)}\right). \tag{34}$$

The two firms will get the same weight on their profits in equilibrium, i.e. $\overline{\varphi}_i^C \equiv \overline{\varphi}^C$, $i = 1, 2$.

An important consequence of this analysis, which can be simply obtained by comparing (32) and (34), is the following.

Proposition 6 *In an interior equilibrium,* $\Delta\overline{\varphi}(z) \equiv \overline{\varphi}^D - \overline{\varphi}^C(z) : [0,1) \to (-1,0)$*, i.e. the weight of profits in the regulatory objective function is higher under centralization. Moreover,* $\Delta\overline{\varphi}(z)$ *is*

(a) (strictly) decreasing, i.e. $\frac{\partial\Delta\overline{\varphi}(z)}{\partial z} < 0$ *for* $z \in (0,1)$

(b) (strictly) concave, i.e. $\frac{\partial^2\Delta\overline{\varphi}(z)}{\partial z^2} < 0$.

The proof is quite straightforward. Proposition 6 stresses that a single regulator is *more* distorted to firms' interests than two noncooperative agencies. As already pointed out, centralization introduces an implicit element of competition between the firms in the political market. Each firm is actually engaged in a sort of competition when lobbying the regulator because a higher weight on its profits implies a higher output level at the expense of the other firm (see (29)) and then a higher informational rent. This induces each firm to exert a larger lobbying effort than under decentralization, which yields a profit weight that rises at an increasing rate with substitutability (points (a) and (b)).

4.4. Welfare comparisons

Following the same procedure as in the case of complete information, let us now compare the welfare of each agent under the two regimes and derive some policy suggestions. Notice that the above considerations imply that there is a significant trade-off to be considered. In a sense, centralization is "obviously" preferable under complete information, in that a benevolent regulator will be better able to achieve the social goals when the actions in the two markets are fully coordinated. However, things may be different under asymmetric information. This is especially true as centralization spurs lobbying activity. This may be self-defeating: the very notion of a benevolent regulator is undermined by firms' pressures.

Let us start comparing price levels, which will prove to be crucial to the overall results. After defining $\psi \equiv \alpha - c - \left(1 - \overline{\varphi}^D\right) H$ (with $\psi > 0$ as $\overline{q}^D > 0$), we derive from (26) and (28) the difference in equilibrium prices between the two regimes, which it is useful to write as

$$\overline{p}^D - \overline{p}^C \equiv \Delta\overline{p} = -z\psi - \Delta\overline{\varphi}(z) H = -\overline{I}(z) + \overline{L}(z), \tag{35}$$

where

$$\overline{I}(z) = z\psi \geq 0 \tag{36}$$

and

$$\overline{L}(z) = -\Delta\overline{\varphi}(z) H \geq 0, \tag{37}$$

which is non-negative by Proposition 6. This shows that the impact of substitutability on equilibrium prices is now twofold. The first term in (35), i.e. $\overline{I}(z)$, captures the "*(direct) market interdependence effect*" under asymmetric information, which yields lower prices under decentralization, as in the case of complete information. The "*lobbying effect*", represented by $\overline{L}(z)$, can be seen as a second, indirect effect of substitutability, one which plays a role only in case of asymmetric information and which entails that prices under centralization are lower than under decentralization. A single regulator will be exposed to greater lobbying activity and will thus be more profit oriented; therefore, she will decrease prices in order to increase production and distribute higher informational rents.

Notice from (35) that asymmetric information influences the two effects in the same direction. On the one hand, it mitigates the *market interdependence effect*, by making decentralization less convenient for consumers than under complete information. In fact, this effect is now *weaker* ($\overline{I} < I$), since asymmetric information (even in the absence of any differences in lobbying activities, i.e. $\overline{L} = 0$) involves a higher distortion in decentralized prices (see from (26) and (30) of equilibrium that $(1+z)(1-\varphi) H > (1-\varphi) H$). On the other hand, asymmetric information yields a *lobbying effect*, which makes centralization relatively more desirable for consumers ($\frac{d\overline{L}}{dH} > 0$ by (32) and (34)). Therefore, due to asymmetric information, prices increase in both regimes. However, they rise more under decentralization than under centralization. When this distortion due to asymmetric information is large enough, the full information result in (19) may well be reversed.

In order to better understand the situation and to establish our main results, it is useful to first consider the following intermediate step.

Lemma 7 *Define the function* $\Gamma(z) : [0, 1) \rightarrow R$ *as* $\Gamma(z) \equiv \overline{L}(z) - \overline{I}(z) = -\Delta\overline{\varphi}(z) H - z\psi$*. Then, the following is true:*

(a) $\Gamma(0) = 0$

(b) $\Gamma(.)$ *is initially (strictly) decreasing, i.e.* $\Gamma'(0) < 0$*, and then (strictly) increasing, i.e* $\Gamma'(z) > 0$ *for* z *large enough*

(c) $\Gamma(.)$ *is (strictly) convex, i.e.* $\Gamma'' > 0$

(d) if $H > -\frac{z\psi}{\Delta\overline{\varphi}(z)}$ *for some* $z \in (0, 1)$ *there exists a unique value of* z *(call it* z^**) such that* $\Gamma(z^*) = 0$

(e) $\Gamma(z) > 0$ *if and only if* $z \in (z^*, 1)$*.*

Parts (a) to (c) are straightforward consequences of the definitions of ψ and $\Delta\overline{\varphi}(z)$ (see Proposition 6). Point (d) stresses that only if the lobbying effect, when reaching its maximum value (i.e. for z sufficiently high), can offset the market interdependence effect ($\Gamma(.) > 0$), then a trade-off between the two effects emerges. This occurs when asymmetric information is a particularly relevant issue ($H > -\frac{z\psi}{\Delta\overline{\varphi}(z)}$). Otherwise, the market interdependence effect always outweighs the lobbying effect and regulatory centralization remains preferable, as with complete information (see also Proposition 8).

For this reason, we focus hereafter on the case in which a threshold value $z^* \in (0, 1)$ exists. The immediate implication of Lemma 7 is that decentralization decreases equilibrium prices as long as substitutability among the goods is not too high, i.e. $z < z^*$. We are now in a position to state our main results, which we will then discuss in different steps.

Proposition 8 *Assume that* $z \in (z^*, 1)$*, which implies* $\overline{L}(z) > \overline{I}(z)$*. Then, under asymmetric cost information, regulatory decentralization*

i) decreases consumer surplus, i.e. $\overline{CS}^D < \overline{CS}^C$

ii) decreases profits, i.e. $\overline{\pi}^D < \overline{\pi}^C$

iii) decreases subsidies, i.e. $\overline{S}^D < \overline{S}^C$

iv) increases social welfare, i.e. $\overline{W}^D > \overline{W}^C$*.*

Otherwise, the opposite holds.

This result confirms the implications of our complete information analysis, with the additional trade-off brought about by the lobbying effect. Because of asymmetric information, lobbying becomes potentially effective, and we have seen that decentralization decreases the incentive to lobby (see Proposition 6).

In particular, an increase in the degree of substitutability between goods yields a stronger lobbying effect under centralization, since each firm has a greater incentive to lobby the unique regulator (see (34)). Notice that the lobbying effect increases with z faster than the market interdependence effect. In fact, while the impact of substitutability on the latter effect is constant (equal to ψ), the weight on profits under centralization increases at an increasing rate because the competition in the political market for lobbying the regulator becomes tougher and tougher.[16] When goods are closer substitutes, i.e. if $z \in (z^*, 1)$, the strength of the lobbying effect induces the Congress to prefer decentralization.

Most calculations for the proof of the different parts in Proposition 8 are shown in Appendix F, where we examine each component of the welfare function, which is expressed as the difference between its value under decentralization and under centralization. More precisely, in all cases, we are able to write the difference between decentralization and centralization as the sum of three terms: the full information difference, the additional market interdependence effect under asymmetric information and the lobbying effect.

Consumers are better off under the regime which grants the lower prices, and so are firms, as their rents depend positively on output levels. As the rents largely come from taxpayers, this category's interest goes in the opposite direction. Not surprisingly, the latter group's interest prevails. Notice that the contrast of interests between consumers and shareholders, on the one hand, and taxpayers, on the other hand, appears in the whole regulation literature since Baron and Myerson [**5**]. Relative to a single market regulation, here we can compare two different regimes and this comparison highlights things, which in other analyses remain implicit.

This result suggests that with more interdependent markets a decentralized regime turns out to be a reasonable structural response to non-benevolent regulation since it mitigates the capture problem in the delegation of the regulatory authority. The trade-off between the market interdependence effect and the lobbying effect implies that the welfare gains delivered to taxpayers under decentralization more than compensate the losses to consumers and firms, so that the Congress will find it more desirable to decentralize market regulation.

[16] Notice also that (29) is decreasing in z, which means that the greater substitutability, the bigger is the negative impact of an increase in profit weight of a firm on the quantity (and profit) of the other. This definitely exacerbates the competition between the two firms.

5. Concluding remarks

In this paper we have tackled the problem of how to design the jurisdiction of a regulatory authority when two markets have interdependent demands and there is the threat of regulatory capture.

Our analysis has shown that under complete information centralized (cooperative) regulation is the best solution in terms of social welfare. This intuitive result covers a distributional aspect of great interest. Two noncooperative agencies, each regulating a single market, set lower prices than a single authority and the higher quantities produced in equilibrium increase consumer welfare. This market interdependence effect definitely benefits consumers, but it reduces social welfare.

However, these results may no longer hold under asymmetric cost information as a unique regulator is more distorted to firms' interests as a result of lobbying activities. In this case, a trade-off emerges in equilibrium between the market interdependence effect and the lobbying effect. When the substitutability between goods is high enough, the latter effect outweighs the former and decentralizing the regulatory structure turns out to be social welfare enhancing. Hence, a decentralized (noncooperative) regime can be a good response to the non-benevolent regulation since it alleviates the capture problem.

We believe that much scope exists for future research in this field and our model can be enriched in a variety of directions. We would like to mention two aspects which are left for future development.

First of all, markets may be also interconnected on the cost side. This occurs when one good enters into the production process of the other. Examples of this kind are given by water and electricity, as the former is an input for the latter.

The second idea concerns the informational framework examined in the paper. While asymmetric cost information is certainly relevant, limited regulatory knowledge about market demands would be equally interesting to consider, especially when demands are interdependent.

We believe that a greater effort in these directions might shed some light on many other important issues.

Appendix A

After replacing the choice variable S_i with π_i from (4), the regulator's optimization problem in (10) may be written as follows

$$\max_{q_i,\pi_i} \alpha q_i + \alpha q_j - \frac{1}{2}\left(\beta q_i^2 + 2\gamma q_i q_j + \beta q_j^2\right)$$

$$-p_j(q_i,q_j)\cdot q_j - C_i(q_i) - S_j - \left(1-\varphi_i^D\right)\pi_i \quad s.t.\ (PC_i). \tag{38}$$

Since (38) is decreasing in π_i, firm i gets zero profits in equilibrium ($\pi_i^D = 0$).

Maximizing (38) with respect to q_i yields the following first-order condition

$$\alpha - \beta q_i - c_i = 0.$$

Appendix B

We replace the choice variables S_1 and S_2 from (4) with π_1 and π_2, respectively. The regulator's optimization program in (14) may be rewritten as follows

$$\max_{q_1,q_2,\pi_1,\pi_2} \alpha q_1 + \alpha q_2 - \frac{1}{2}\left(\beta q_1^2 + 2\gamma q_1 q_2 + \beta q_2^2\right) - C_1(q_1)$$

$$-C_2(q_2) - \left(1-\varphi_1^C\right)\pi_1 - \left(1-\varphi_2^C\right)\pi_2 \quad s.t.\ (PC_1), (PC_2). \tag{39}$$

Since (39) is decreasing in π_1 and π_2, the two firms get zero profits in equilibrium ($\pi_1^C = \pi_2^C = 0$). Maximizing (39) with respect to q_i, $i = 1, 2$, yields the following first-order condition

$$\alpha - \beta q_i - \gamma q_j - c_i = 0.$$

Appendix C

We derive the local necessary incentive compatibility condition (ICC$_i$) seen in Section 4 and show that this condition is also globally sufficient for the cost specification in (5) if $q_i(.)$ is non-increasing in c_i.

The set of global incentive compatible mechanisms satisfies for any $c_i, \widehat{c}_i \in [c^-, c^+]$ the following constraint

$$\int_{c^-}^{c^+} \pi_i(c_i, c_i; c_j) f(c_j)\, dc_j \equiv \int_{c^-}^{c^+} \pi_i(c_i; c_j) f(c_j)\, dc_j \geq \int_{c^-}^{c^+} \pi_i(\widehat{c}_i, c_i; c_j) f(c_j)\, dc_j. \tag{40}$$

Condition (40) requires that firm i does not have any incentive to misrepresent its private information, since the expected profit $\int_{c^-}^{c^+} \pi_i(c_i; c_j) f(c_j) dc_j$ received by revealing truthfully its marginal costs $c_i \in [c^-, c^+]$ is at least as great as the expected profit $\int_{c^-}^{c^+} \pi_i(\widehat{c}_i, c_i; c_j) f(c_j) dc_j$ it could obtain for any report $\widehat{c}_i$.

Following the Baron [**4**] approach and using (4) and (5), the right-hand side of (40) may be rewritten as

$$\int_{c^-}^{c^+} \pi_i(\widehat{c}_i, c_i; c_j) f(c_j) dc_j$$

$$= \int_{c^-}^{c^+} [\pi_i(\widehat{c}_i; c_j) + C_i(q_i(\widehat{c}_i), \widehat{c}_i) - C_i(q_i(\widehat{c}_i), c_i)] f(c_j) dc_j, \tag{41}$$

where $\pi_i(\widehat{c}_i; c_j) \equiv \pi_i(\widehat{c}_i, \widehat{c}_i; c_j)$. After substituting (41) into (40), we get

$$\int_{c^-}^{c^+} [\pi_i(c_i; c_j) - \pi_i(\widehat{c}_i; c_j)] f(c_j) dc_j$$

$$\geq \int_{c^-}^{c^+} [C_i(q_i(\widehat{c}_i), \widehat{c}_i) - C_i(q_i(\widehat{c}_i), c_i)] f(c_j) dc_j. \tag{42}$$

Reversing the roles of c_i and $\widehat{c}_i$ in (40) and (41) yields

$$\int_{c^-}^{c^+} [\pi_i(c_i; c_j) - \pi_i(\widehat{c}_i; c_j)] f(c_j) dc_j$$

$$\leq \int_{c^-}^{c^+} [C_i(q_i(c_i), \widehat{c}_i) - C_i(q_i(c_i), c_i)] f(c_j) dc_j. \tag{43}$$

Combining (42) and (43) implies

$$\int_{c^-}^{c^+} [C_i(q_i(\widehat{c}_i), \widehat{c}_i) - C_i(q_i(\widehat{c}_i), c_i)] f(c_j) dc_j$$

$$\leq \int_{c^-}^{c^+} \left[\pi_i\left(c_i; c_j\right) - \pi_i\left(\widehat{c}_i; c_j\right)\right] f\left(c_j\right) dc_j$$

$$\leq \int_{c^-}^{c^+} \left[C_i\left(q_i\left(c_i\right), \widehat{c}_i\right) - C_i\left(q_i\left(c_i\right), c_i\right)\right] f\left(c_j\right) dc_j. \tag{44}$$

Dividing the inequalities in (44) by $\widehat{c}_i - c_i$ for $\widehat{c}_i > c_i$ and taking the limit as $\widehat{c}_i \to c_i$ yields

$$\int_{c^-}^{c^+} \frac{d\pi_i\left(c_i; c_j\right)}{dc_i} f\left(c_j\right) dc_j = -\int_{c^-}^{c^+} \frac{\partial C_i\left(c_i, .\right)}{\partial c_i} f\left(c_j\right) dc_j. \tag{45}$$

After integrating both sides of equation (45) over $[c_i, c^+]$ and combining terms, we obtain the local necessary incentive compatibility condition (ICC$_i$) seen in Section 4

$$\int_{c^-}^{c^+} \pi_i\left(c_i; c_j\right) f\left(c_j\right) dc_j = \int_{c^-}^{c^+} \pi_i\left(c^+, c_j\right) f\left(c_j\right) dc_j + \int_{c^-}^{c^+}\int_{c_i}^{c^+} \frac{\partial C_i\left(\widetilde{c}_i, .\right)}{\partial \widetilde{c}_i} d\widetilde{c}_i f\left(c_j\right) dc_j. \tag{46}$$

Now we show that condition (46) is also globally sufficient for the cost function in (5) if $q_i\left(.\right)$ is non-increasing in c_i. Plugging $\int_{c^-}^{c^+} \pi_i\left(\widehat{c}_i; c_j\right) f\left(c_j\right) dc_j$ from (46) for $\widehat{c}_i = c_i$ into (45) and using (5) yields

$$\int_{c^-}^{c^+} \pi_i\left(\widehat{c}_i, c_i; c_j\right) f\left(c_j\right) dc_j = \int_{c^-}^{c^+} \pi_i\left(c^+, c_j\right) f\left(c_j\right) dc_j + \int_{c^-}^{c^+}\int_{\widehat{c}_i}^{c^+} q_i\left(\widetilde{c}_i\right) d\widetilde{c}_i f\left(c_j\right) dc_j$$

$$+ \int_{c^-}^{c^+} \left(\widehat{c}_i - c_i\right) q_i\left(\widehat{c}_i\right) f\left(c_j\right) dc_j. \tag{47}$$

If we replace $\int_{c^-}^{c^+} \pi_i\left(c^+, c_j\right) f\left(c_j\right) dc_j$ from (46) into (47), we get after some manipulations

$$\int_{c^-}^{c^+} \pi_i\left(\widehat{c}_i, c_i; c_j\right) f\left(c_j\right) dc_j = \int_{c^-}^{c^+} \pi_i\left(c_i; c_j\right) f\left(c_j\right) dc_j - \int_{c^-}^{c^+}\int_{c_i}^{\widehat{c}_i} q_i\left(\widetilde{c}_i\right) d\widetilde{c}_i f\left(c_j\right) dc_j$$

$$+\int_{c^-}^{c^+} (\widehat{c}_i - c_i)\, q_i(\widehat{c}_i)\, f(c_j)\, dc_j. \tag{48}$$

Finally, combining terms in (48) yields

$$\int_{c^-}^{c^+} \pi_i(\widehat{c}_i, c_i; c_j)\, f(c_j)\, dc_j = \int_{c^-}^{c^+} \pi_i(c_i; c_j)\, f(c_j)\, dc_j$$

$$+\int_{c^-}^{c^+}\int_{c_i}^{\widehat{c}_i} [q_i(\widehat{c}_i) - q_i(\widetilde{c}_i)]\, d\widetilde{c}_i f(c_j)\, dc_j. \tag{49}$$

The global incentive compatibility condition in (49) is satisfied for any $c_i, \widehat{c}_i \in [c^-, c]$ if the second term on the right-hand side in (49) is non-positive. Our claim is that this occurs if $q_i(.)$ is non-increasing in c_i. To see why such is the case, notice that, if $\widehat{c}_i \geq c_i$, then the (weak) monotonicity of $q_i(.)$ implies that the integral in (49) is non-positive. When $\widehat{c}_i < c_i$, then the term in square brackets in (49) is nonnegative if $q_i(c_i)$ is a non-increasing function but reversing the direction of the integral implies that the second term in (49) is non-positive. Therefore, the local necessary incentive compatibility condition (ICC_i) in (46) is also globally sufficient for the cost specification in (5) provided that $q_i(.)$ is non-increasing in c_i (sufficient condition for this is the increasing hazard rate property).

Appendix D

We replace the choice variable $S_i(c_i)$ with $\pi_i(.)$ from (4) as shown in Appendix A. Then, substituting (ICC_i) into (24) and integrating by parts yields

$$\max_{q_i(c_i),\pi_i(c^+,.)} \int_{c^-}^{c^+}\int_{c^-}^{c^+} \Big[\alpha q_i(c_i) + \alpha q_j(c_j) - \frac{1}{2}\left(\beta q_i^2(c_i) + 2\gamma q_i(c_i)\cdot q_j(c_j) + \beta q_j^2(c_j)\right)$$

$$-p_j(q_i(c_i), q_j(c_j))\cdot q_j(c_j) - C_i(q_i(c_i)) - S_j$$

$$-\left(1-\varphi_i^D\right)\cdot\left(\frac{F(c_i)}{f(c_i)} q_i(c_i) + \pi_i\left(c^+,.\right)\right)\Big] f(c_i)\, f(c_j)\, dc_i dc_j \quad s.t. \tag{50}$$

$$\int_{c^-}^{c^+} \pi_i\left(c^+,.\right) f\left(c_j\right) dc_j \geq 0. \tag{PC$_i$}$$

Since (50) is decreasing in $\int_{c^-}^{c^+} \pi_i\left(c^+,.\right) f\left(c_j\right) dc_j$, the regulator finds it optimal to give zero (expected) profit to the most inefficient firm.

Maximizing pointwise (50) with respect to $q_i\left(.\right)$ yields the following first-order condition

$$\int_{c^-}^{c^+} \left[\alpha - \beta q_i\left(c_i\right) - c_i - \left(1 - \varphi_i^D\right) \frac{F\left(c_i\right)}{f\left(c_i\right)}\right] f\left(c_j\right) dc_j = 0.$$

Appendix E

We replace the choice variable $S_i\left(c_1, c_2\right)$ with $\pi_i\left(.\right)$ from (4) as shown in Appendix B. Then, substituting (ICC_1) and (ICC_2) into (27) and integrating by parts yields

$$\max_{q_1(c_1,c_2),q_2(c_1,c_2),\pi_1(c^+,.),\pi_2(c^+,.)} \int_{c^-}^{c^+}\int_{c^-}^{c^+} \left[\alpha q_1\left(c_1, c_2\right) + \alpha q_2\left(c_1, c_2\right)\right.$$

$$-\frac{1}{2}\left(\beta q_1^2\left(c_1, c_2\right) + 2\gamma q_1\left(c_1, c_2\right) \cdot q_2\left(c_1, c_2\right) + \beta q_2^2\left(c_1, c_2\right)\right) - C_1\left(q_1\left(c_1, c_2\right)\right)$$

$$-C_2\left(q_2\left(c_1, c_2\right)\right) - \left(1 - \varphi_1^C\right) \cdot \left(\frac{F\left(c_1\right)}{f\left(c_1\right)} q_1\left(c_1, c_2\right) + \pi_1\left(c^+,.\right)\right)$$

$$\left. - \left(1 - \varphi_2^C\right) \cdot \left(\frac{F\left(c_2\right)}{f\left(c_2\right)} q_2\left(c_1, c_2\right) + \pi_2\left(c^+,.\right)\right)\right] f\left(c_1\right) f\left(c_2\right) dc_1 dc_2 \quad s.t. \tag{51}$$

$$\int_{c^-}^{c^+} \pi_1\left(c^+,.\right) f\left(c_2\right) dc_2 \geq 0$$

$$\int_{c^-}^{c^+} \pi_2\left(c^+,.\right) f\left(c_1\right) dc_1 \geq 0.$$

As (51) decreases in $\int_{c^-}^{c^+} \pi_1(c^+, .) f(c_2) dc_2$ and $\int_{c^-}^{c^+} \pi_2(c^+, .) f(c_1) dc_1$, the firms with the highest costs obtain zero (expected) profits in equilibrium.

Maximizing pointwise (51) with respect to $q_i(.)$ yields the following first-order condition

$$\alpha - \beta q_i(c_i, c_j) - \gamma q_j(c_i, c_j) - c_i - \left(1 - \varphi_i^C\right) = 0.$$

Appendix F

F.1. Consumer surplus

Substituting (25) and (28) of equilibrium into (2) we find after some manipulations the (expected) difference in consumer surplus between decentralization and centralization. This is given by

$$E\left(\overline{CS}^D - \overline{CS}^C\right) \equiv \Delta E\left(\overline{CS}\right) = \frac{1}{\beta(1+z)} \int_{c^-}^{c^+}\int_{c^-}^{c^+} \left[z(2+z)\psi^2 + \right.$$

$$\left. + \Delta\overline{\varphi}(z) H (2\psi - \Delta\overline{\varphi}(z) H)\right] f(c_1) f(c_2) dc_1 dc_2. \tag{52}$$

This can be written as:

$$E\left(\overline{CS}^D - \overline{CS}^C\right) \equiv \Delta E\left(\overline{CS}\right) = z\frac{2+z}{\beta(1+z)}(\alpha - c)^2 +$$

$$-z\frac{2+z}{\beta(1+z)} \int_{c^-}^{c^+}\int_{c^-}^{c^+} \left(1 - \overline{\varphi}^D\right) H (\psi + \alpha - c) f(c_1) f(c_2) dc_1 dc_2 +$$

$$+\frac{1}{\beta(1+z)} \int_{c^-}^{c^+}\int_{c^-}^{c^+} \Delta\overline{\varphi}(z) H (2\psi - \Delta\overline{\varphi}(z) H) f(c_1) f(c_2) dc_1 dc_2. \tag{53}$$

The first two addends in (53) capture the impact of the market interdependence effect on consumer surplus. The first one is the full information differential in (21), while the second one is the asymmetric information effect purely due to market interdependence. Notice that entire expression is lower than under complete information but it is still positive, since it is derived by exploiting the definition of ψ. The third term in (53) comes from the lobbying effect and acts in the opposite direction (as $\Delta\overline{\varphi}(z) \leq 0$), since a more profit-oriented single regulator benefits consumers by increasing production in order to distribute higher informational rents.

Substituting (36) and (37) into (52) we find after some computations that the integrand is positive (which implies that decentralization makes consumers *ex post* better off) if and only if

$$\Delta\overline{CS} = \left(\overline{I}(z) - \overline{L}(z)\right)\left(\overline{I}(z) + \overline{L}(z) + 2\psi\right) > 0. \tag{54}$$

It is immediate to see that (54) is satisfied if $\overline{I}(z) > \overline{L}(z)$. Therefore, consumers are (*ex post*) better off under decentralization if and only if $z < z^*$, i.e. when the market interdependence effect is stronger than the lobbying effect.

F.2. Profits

Replacing (25) and (28) of equilibrium into (ICC), we find that the (expected) difference in profits for each firm between the two regulatory regimes is given by

$$E\left(\overline{\pi}^D - \overline{\pi}^C\right) \equiv \Delta E(\overline{\pi})$$

$$= \frac{1}{\beta(1+z)} \int_{c^-}^{c^+}\int_{c^-}^{c^+}\int_{c}^{c^+} \left[z\psi + \Delta\overline{\varphi} H(\widetilde{c})\right] d\widetilde{c} f(c_1) f(c_2)\, dc_1 dc_2$$

$$= \frac{1}{\beta(1+z)} \int_{c^-}^{c^+}\int_{c^-}^{c^+} H\left(z\psi + \Delta\overline{\varphi}(z) H\right) f(c_1) f(c_2)\, dc_1 dc_2, \tag{55}$$

where the second equality is derived through integration by parts.

From (55) we can see that decentralization benefits (*ex post*) firms when $\overline{I}(z) > \overline{L}(z)$, i.e. if $z < z^*$, since firms produce more and get higher informational rents. Notice that the two effects play exactly the same role as in consumer surplus.

F.3. Subsidies

Substituting equilibrium outputs in (25) and (28) into (4), we obtain after some manipulations the (expected) difference in subsidies between the two regulatory regimes, which is given by

$$E\left(\overline{S}^{D}-\overline{S}^{C}\right)\equiv\Delta E\left(\overline{S}\right)$$

$$=\frac{1}{\beta\left(1+z\right)}\int_{c^-}^{c^+}\int_{c^-}^{c^+}\left\{z\psi\left[\left(1+z\right)\psi+\overline{\varphi}^{D}H\right]\right.$$

$$\left.+\Delta\overline{\varphi}\left(z\right)H\left(\psi+\overline{\varphi}^{C}\left(z\right)H\right)\right\}f\left(c_1\right)f\left(c_2\right)dc_1dc_2. \qquad (56)$$

We can rewrite (56) as follows

$$\Delta E\left(\overline{S}\right)=\frac{z}{\beta}\left(\alpha-c\right)^2$$

$$-\frac{z}{\beta\left(1+z\right)}\int_{c^-}^{c^+}\int_{c^-}^{c^+}\left[\left(1+z\right)\left(1-\overline{\varphi}^{D}\right)\left(\alpha-c+\psi\right)-\overline{\varphi}^{D}\psi\right]Hf\left(c_1\right)f\left(c_2\right)dc_1dc_2$$

$$+\frac{1}{\beta\left(1+z\right)}\int_{c^-}^{c^+}\int_{c^-}^{c^+}\Delta\overline{\varphi}\left(z\right)H\left(\psi+\overline{\varphi}^{C}\left(z\right)H\right)f\left(c_1\right)f\left(c_2\right)dc_1dc_2. \qquad (57)$$

The first two terms reflect the impact of the market interdependence effect on subsidies. This is the difference between the full information differential in (22) and the distortion due to asymmetric information. This expression is positive as with complete information, which implies that the market interdependence effect still induces more subsidization under decentralization. However, the sign of the second term is ambiguous. When $\overline{\varphi}^{D}$ is low enough it is positive, which implies a lower extra subsidization under decentralization relative to the case of complete information. The rationale is that the higher prices (see the second term in (26)) allow two different regulators to subsidize relatively less production. When $\overline{\varphi}^{D}$ is high the second term in (57) becomes negative, which implies that the extra subsidization under decentralization is even greater than with complete information. The third term in (57) represents the impact of lobbying on subsidies and shows that a unique regulator, which cares more about the industry's interests, gives firms higher transfers.

Plugging (36) and (37) into (56) we find after some manipulations that the integrand is negative (which implies that decentralization makes taxpayers *ex post* better off) if and only if

$$\Delta\overline{S}=\left(\overline{L}\left(z\right)-\overline{I}\left(z\right)\right)\left(\overline{L}\left(z\right)+\overline{I}\left(z\right)+\psi+\overline{\varphi}^{D}H\right)>0. \qquad (58)$$

Notice that (58) holds if $\overline{L}\left(z\right)>\overline{I}\left(z\right)$.

F.4. Social welfare

We compute the (expected) difference in social welfare using (52) and (56). After some manipulations we find

$$\Delta E\left(\overline{W}\right) = \frac{1}{\beta\left(1+z\right)} \int\limits_{c^-}^{c^+}\int\limits_{c^-}^{c^+} \left[-z\psi\left(z\psi + 2H\overline{\varphi}^D\right)\right.$$

$$\left. -\Delta\overline{\varphi}H^2\left(\overline{\varphi}^C\left(z\right)+\overline{\varphi}^D\right)\right] f\left(c_1\right) f\left(c_2\right) dc_1 dc_2. \tag{59}$$

This can be written as

$$E\left(\overline{W}^D - \overline{W}^C\right) \equiv \Delta E\left(\overline{W}\right) = -\frac{z^2}{\beta\left(1+z\right)}\left(\alpha - c\right)^2$$

$$+\frac{z}{\beta\left(1+z\right)} \int\limits_{c^-}^{c^+}\int\limits_{c^-}^{c^+} \left\{zH\left(1-\overline{\varphi}^D\right)\left(\psi+\alpha-c\right) - 2\psi\overline{\varphi}^D H\right\} f\left(c_1\right) f\left(c_2\right) dc_1 dc_2$$

$$-\frac{1}{\beta\left(1+z\right)} \int\limits_{c^-}^{c^+}\int\limits_{c^-}^{c^+} \Delta\overline{\varphi}H^2\left(\overline{\varphi}^C\left(z\right)+\overline{\varphi}^D\right) f\left(c_1\right) f\left(c_2\right) dc_1 dc_2. \tag{60}$$

The sum of the first two terms represents the overall impact of the market interdependence effect on social welfare. The full information result in (23) is modified by a term (the double integral in the second line) whose sign depends on the value of $\overline{\varphi}^D$. If the latter is low enough, that term is positive, so the undesirability of decentralization driven by market interdependence is reduced, even though it persists. On the contrary, if $\overline{\varphi}^D$ is high the term in the second line becomes negative, which means that asymmetric information makes decentralization even more detrimental. The third term in (60) denotes the impact of the lobbying effect on social welfare. The higher this effect, the more desirable becomes decentralized regulation, which dampens the amount of subsidies and the firms' profits, both costly in social welfare terms.

If we insert (36) and (37) into (59) we find after some algebra that the integrand is positive (which implies that decentralization is *ex post* social welfare improving) if and only if

$$\Delta\overline{W} = \left(\overline{L}\left(z\right) - \overline{I}\left(z\right)\right)\left(\overline{L}\left(z\right) + \overline{I}\left(z\right) + 2\overline{\varphi}^D H\right) > 0, \tag{61}$$

which is satisfied when $\overline{L}\left(z\right) > \overline{I}\left(z\right)$.

If the market interdependence effect offsets the lobbying effect, then we get the same result as under complete information, and the Congress still prefers centralization. This occurs when goods are quite imperfect substitutes, i.e. if $z \in (0, z^*)$. However, when the substitutability between goods is higher, i.e. if $z \in (z^*, 1)$, the lobbying effect prevails and the distortion to firms' interests becomes a serious issue under centralization.

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